Development of Landslide at CSA-Open Mine in Bohemia

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SYNOPSIS Because of its descriptive properties physical modelling belongs to one of the most prospective means for assesment of behaviour of soils and rocks. Its disadvantage is a poor description of stress fields in the material. This difficulty can be partly avoid by means of mathematical modelling mainly by comparision of both the models. The coupled modelling brings also about new views on the statements of constitutive relations, here following Drucker, Prager, 1952, also Brož, Procházka, 1987, mathematical background e.g. Duvant, Lions, 1972. For more details of physical modelling see e.g. Vacek, 1991, another application of coupled modelling see e.g. Vacek, Procházka, 1992. The coupled modelling were testified on the landslide described in the sequel.

INTRODUCTION

Landslides cannot be considered a static phenomenon but it is necessary to take into account time dependant history of failure of the slope under consideration. During the landslide the moving rock splits into blocks and its shape changes considerably. The deformation of the landslide reaches often hundreds of meters and the slide holds in moving several months. Untill the failure of the slope the problem can be solved mathematically, the deformation and stress state in mass is stated and can be compared with both experimental and in situ data. After the failure mathematical treatment was combersome and this is why the experimental investigetion on models from physically equivalent materials was used. The mining workers were interested in a behaviour of open mine slopes in the region. Therefore, it was necessary to calibrate materials for experimental use which approved a similar behaviour of the model and the reality. For this reason the case history of landslide of slope Jansky vrch (locality from the region under consideration) from January 1990 was treated.

In our modelling the first, stable, stages of excavation are modelled by the mathematical model described in third chapter and in the fourth one the unstable stages, after viewable movements occured, are studied.

1. GEOLOGICAL SITUATION

Geological situation is depicted in Fig.1.

The nature of the layers and model properties are described in Table 1 and Table 2 where φ is angle of internal friction and c cohesion and E modul of elasticity.

2. MODEL CALIBRATION AND CONSTRUCTION

The behaviour of the model was calibrated on four preliminary models on which the agreement of deformation process of failure in the reality and model was verified. The agreement was attained due to improvement of the model material properties. Especially, the function of predestinated slide strata, agreement of

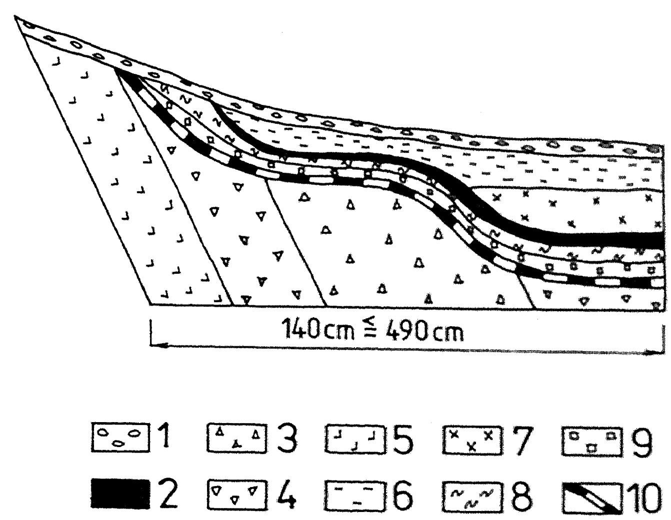

Fig. 1 Scheme of the trial model of CSA open-pit mine

1. debris 2. clay 3. claystone 4. coal 5. claystone 6. sandy clay 7. strong altered gneiss 8. altered gneiss 9. gneiss 10. predestinated clay slide surface.

TABLE 1

Rock	in situ properties		model properties	
	c [MPa]	φ [deg.]	c [kPa]	φ [deg.]
debris	0.0	25	0.0	25
overburden clay	0.2	17	0.6	17
overburden claystone	0.3	19	0.9	19
bedrock claystone	0.2	25	0.6	25
bedrock sandy clay	0.3	30	0.9	30
slip surface	0.002	2.5	0.006	2.5
coal	0.05	33	0.15	33

TABLE 2

Crystallinikum	in situ properties			model* properties		
	c [MPa]	φ [deg]	E [MPa]	c [kPa]	φ [deg]	E [kPa]
strong altered gneiss	17	26	1100	10	26	570
altered gneiss	33	35	2000	19	35	1140
gneiss	50	40	3500	29	40	2000

*effect of non-modelled fractures and joints involved

final shape of slide in reality and on the model and a blocking of failured rock was studied. The model was build up to accept the following conditions.

- The model was build up in scale 1:350 as a plane case
- Length of the model was 180 cm, height was 90 cm and width was 29 cm
- Gneiss was simulated as a mixture of sand, cement and water, bedrock claystone was made from sand, gypsum and water, overburden claystone from mixture of sand and color, debris was build up from hoarse sand and the sliding strate from adapted expoxide resin
- In crystallinicum rock some of the fractures and joints are modelled with the aim of spatula and these that were not possible to model in this way were respected in virtue of reduction of their properties.
- Mining works were carried out gradually and the individual stages of the modelling were photographed by a special adapted phototheodolit on glass negatives of 13 x 18 cm^2.
- The deformation of the model was measured by the method of close-range photogrammetry.

3. MATHEMATICAL MODELLING

The problem to be solved obeys the following equations:

$$\sigma_{ij,j} + b_i = 0 \quad \text{in } \Omega \quad \varepsilon_{ij}(u) = A_{ijkl}\sigma_{kl} + \lambda_{ij},$$

$$2\varepsilon_{ij} = u_{i,j} + u_{j,i}$$

$$u_i = u_i^\circ \quad \text{in } \Gamma_u, \qquad \sigma_{ij,j} = p_i^\circ \quad \text{in } \Gamma_p \tag{1}$$

$$\lambda_{ij}(\tau_{ij} - \sigma_{ij}) \le 0, \text{ for each } \tau \in V_\sigma^k,\ G(\tau) \le 0 \tag{2}$$

where $\Omega \in \mathbb{R}^k$, $k = 2,3$ is domain with Lipschitz continuous boundary $\Gamma = \Gamma_u \cup \Gamma_p \cup \Gamma_c$, see Fig. 2, on Γ_c Mohr-Coulomb conditions are respected (in our case slip condition is violated all along this part of boundary so that

$$u_n = 0, \quad p_t = -\left(|p_n| \operatorname{tg}\varphi + c\right) \operatorname{signum} u_t. \tag{3}$$

$\sigma = \{\sigma_{ij}\}$ is stress tensor, $\varepsilon = \{\varepsilon_{ij}\}$ is deformation tensor, $u = \{u_i\}$ is vector of displacements, $\mathbf{A} = \{A_{ijkl}\}$ is tensor of elastic moduli, u° and p° are prescribed values of displacements and tractions, respectively, b is vector of volume forces. V_σ^k is a set of symmetric tensors of dimension k . The domain covers the body of the slope under consideration. Furthermore

$$b \in (L_2(\Omega))^k, A \in (L_\infty(\Omega))^4, p^\circ \in (H^{-\frac{1}{2}}(\Gamma_p))^k, u^\circ \in (H^{\frac{1}{2}}(\Gamma_u))^k$$

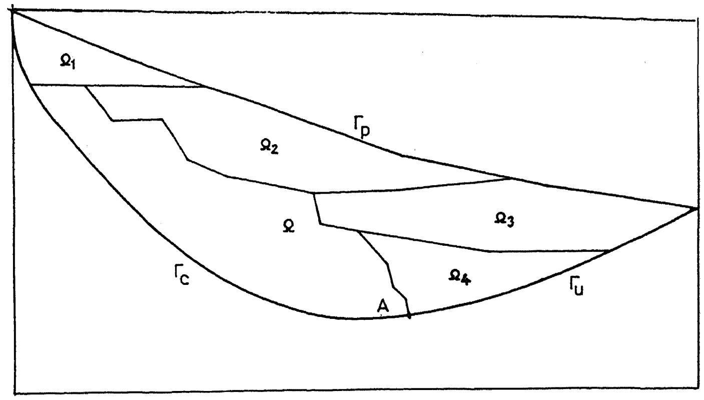

Fig. 2 Geometry of the four trial stages in mathematical modelling: n.stage: $\Omega - \bigcup_{i=1}^{n}\Omega_i$, $n = 1,..,4$

If we introduce sets as follows:

$$U = \{u;\ u \in (H^1(\Omega))^k,\ u = u^\circ \text{ in } \Gamma_u\}$$

$$K = \{\sigma \in V_\sigma^k;\ \sigma_{ij} \in L_2(\Omega);\ G(\sigma) \le 0 \text{ a.e. in } \Omega\}$$

then the problem (1), (2) can be stated as to search the saddle point of Lagrangian

$$l(\sigma,u) = \int_\Omega (\varepsilon_{ij}(u)\sigma_{ij} - b_i u_i)\, dx - a(\sigma,\sigma) - \int_{\Gamma_p} p_i u_i \, d\Gamma \tag{4}$$

where

$$a(\sigma,\sigma) = \tfrac{1}{2}\int_\Omega A_{ijkl}\sigma_{ij}\sigma_{kl}\, dx$$

Denoting

$$J(u) = \sup_{\sigma \in K} l(\sigma,u) \quad \text{in } U \tag{5}$$

we can reformulate the problem in the following manner:

Find

$$\inf_{u \in U} J(u) \tag{6}$$

It is necessary to note that the problem (6) must not posses a solution because of non-coercive property of functional J. One can expect that this case occurs when non-stabil state of the slope is attained. In our case Moreau condition has been taken into consideration in two-dimensional problem:

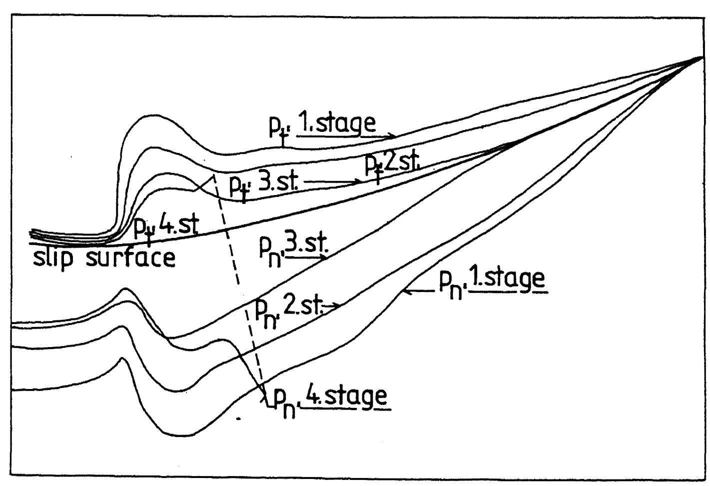

Fig. 3 Distribution of normal p_n and tangential p_t tractions at the separate stages

$$G(\sigma) = \left|\sigma^D\right| + h(\sigma_o) \le 0,\ \sigma_o = \sigma_{11} + \sigma_{22} \qquad (7)$$

specially, Mohr-Coulomb hypothesis has been considered:

$$h(\sigma_0) = \alpha\, \sigma_0 - k,$$

$$\alpha = \sqrt{\frac{\sin^2\varphi}{3(3 + \sin^2\varphi)}}\ ,\ k = c\sqrt{\frac{3}{3 + \sin^2\varphi}}\ \cos\varphi$$

where for φ and c is to be inserted values at yielding state and limit state, respectively. The intermediate values are linearly interpolated.

To verify the assumptions of physical models the following example was solved. Domain Ω describes the body of moving part of the massif, slip boundary coincides with the real slip surface which geometry were obtained from "in situ" measurement. Along the slip boundary the following condition was employed. Along Γ_c in normal direction normal displacement was disabled while in tangential direction tangential traction p_t was equal to negative value of $\left(|p_n|\ \mathrm{tg}\ \varphi + c\right)$ signum u_t and along Γ_u rigid support is considered. Four stages of excavation were respected and distribution of normal traction p_n and tangential traction p_t in these stages are depicted in Fig.3 together with the geometry of Ω. In Fig. 4 the development of safety factor

$$\frac{|p_n|\ \mathrm{tg}\ \varphi + c}{p_t}$$

at points of the slip boundary and in the separate stages is shown. The mathematical model gave a complex view to stress field in the rock and a signalization of another failure can be stated from there.

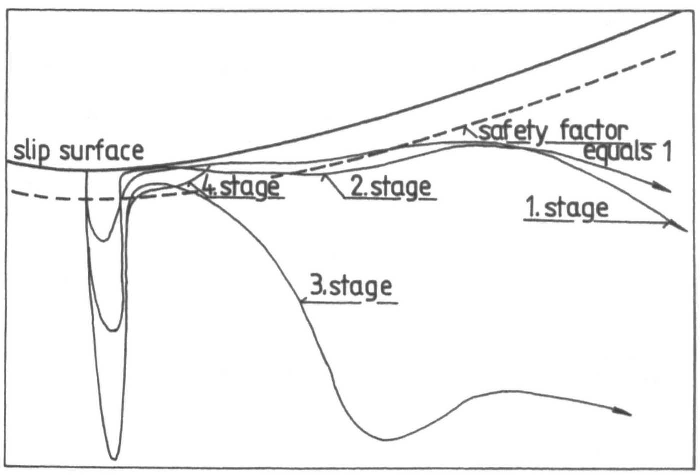

Fig. 4 Distribution of safety factors at the separate stages

4. TEST HISTORY AND MEASURED RESULTS DURING SLIDING

In Fig.1 there is a scheme of the model CSA 02, in Fig.5 there is a photography of the model before testing. Untill the slope failure the mining works followed the real technology of excavation. In Fig.6 through Fig.9 there are choiced stages of slide in detail, in Fig.6 the photography of the still stable slope is shown. This stage corresponds to that when slide commenced. In Fig.7 the first stage of slide, after half an hour, is viewed, in Fig.8 the next stage of slide, after two hours, and, after all, in Fig.9 the final shape of failured slope, after five hours, is illustrated (Note that the real slide at the CSA mine lasted four days). In Fig.10 the blocking of the modelled slide on its picked-up front and the uncovered slide surface behind its top can be seen. The gradual changes of slope surface according to Figs.6 to 9 are shown in Fig. 11.

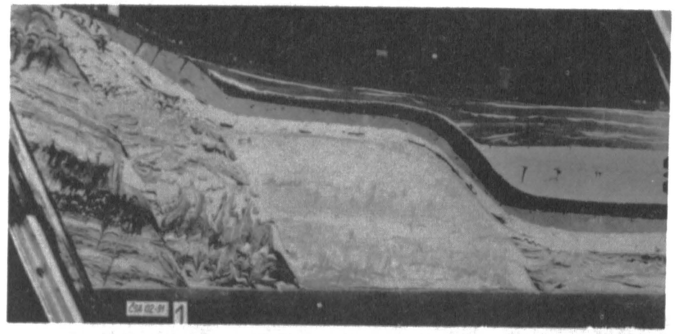

Fig. 5 Photography of the model before testing

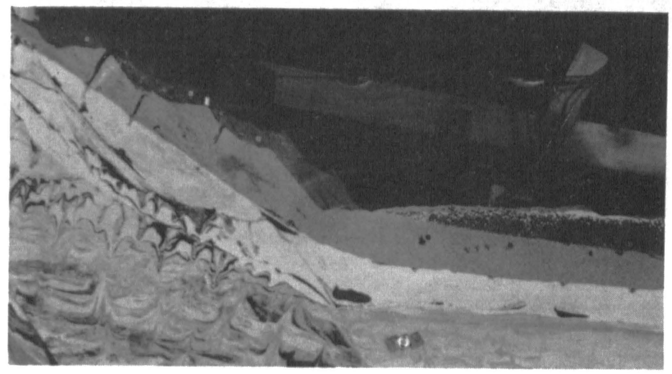

Fig. 6 Detail of the last stable stage of mining

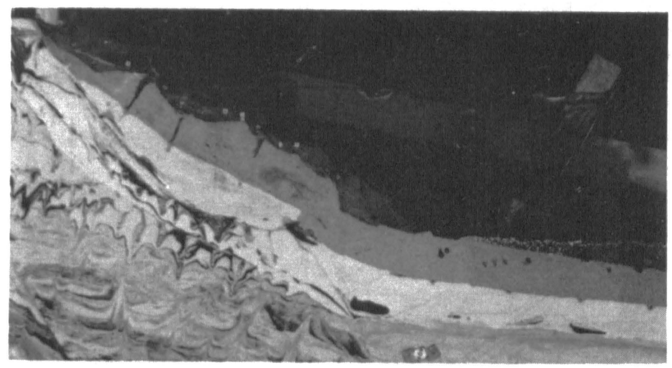

Fig. 7 Development of the slide

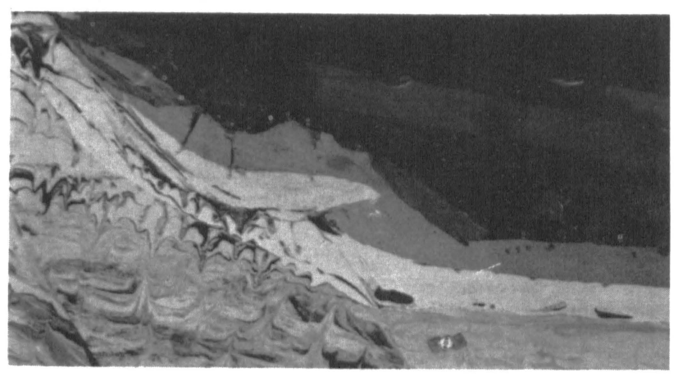

Fig. 8 Next stage of the slide

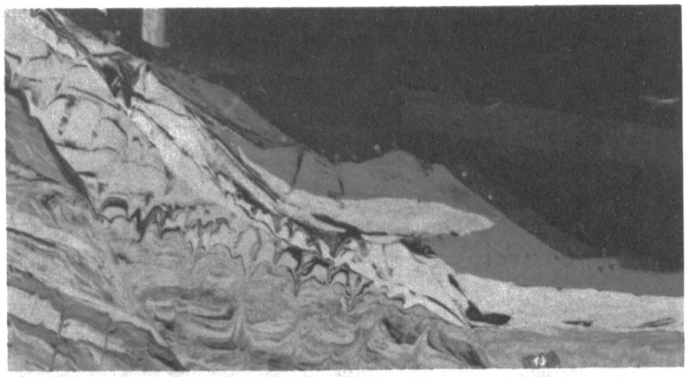

Fig. 9 Final stage of the slide

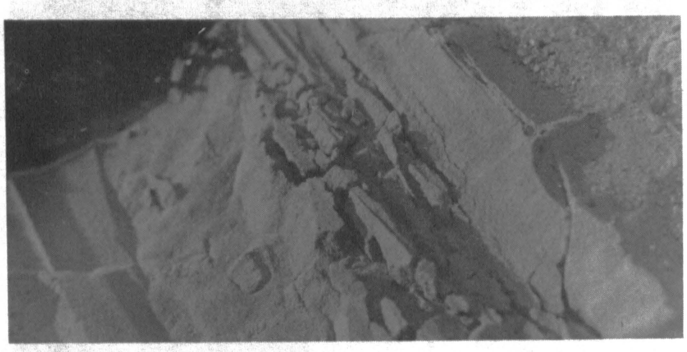

Fig. 10 View from above at the surface of the slide

In Fig.12 the moving of choiced points during sliding in four stages are drawn. From Fig.12 follows that the movement of an arbitrary number of points can be viewed during the sliding process. From the figure immediately follows that the maximum displacements are in the vicinity of the slip surface. This is the probable reason for blocking of the sliding mass.

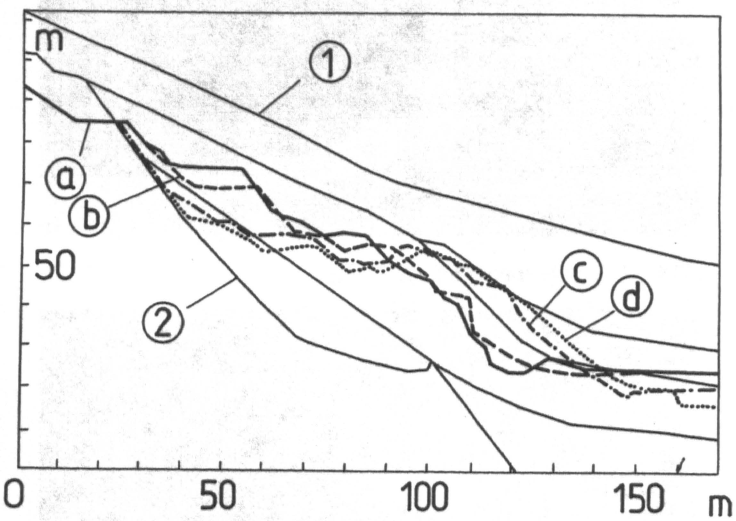

Fig. 11 Changes of rock mass during sliding

1 - the original surface before mining,
2 - predestinated sliding strata
a - surface of rock mass according to Fig.6
b - surface of rock mass according to Fig.7
c - surface of rock mass according to Fig.8
d - surface of rock mass according to Fig.9

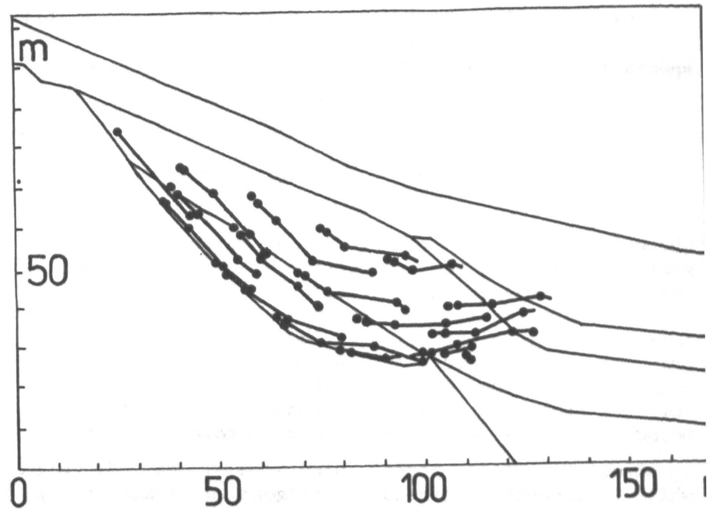

Fig. 12 Movements of selected points in sliding rock mass

CONCLUSION

Our study proved that the procedure of coupled modelling (the mathematical modelling and the physical modelling from equivalent materials) is extraordinary useable for testing of entire mechanizm of failure of slopes (from the beginning of excavation to the final stage of settlement of rock mass movings after failure). The behaviour of both the models were compared with reality and input data were improved by means of calibration process (before the building up of the final physical model four tentative models were studied and their results were compared with in situ slide). It is necessary to note that the results are conditioned by a large analysis which, on the other hand, proposes more general and complex view on the behaviour of the trial slope.

Physical models enable study of movings of slopes after failure and estimation of end states of deformation while mathematical models solve continuum movements under supervision of results obtained from the physical tests. When models are well calibrated the agreement with reality is satisfactory.

REFERENCES

Brož,P.,Procházka,P.(1987), "Boundary Element Method in Engineering" (in Czech), SNTL Praha.

Drucker,D.C.,Prager,W.(1952),"Soil mechanics and plastics analysis or limit design",Quart.Appl.Math. 10: :3: 157-165.

Duvant,G.,Lions,J.L. (1972),"Inequalities in mechanics and physics", Dunod.

Procházka,P.,Vacek,J.(1992),"Determination of Internal Parameters of Open-Cast Slopes by Coupled Modelling", NUMEG'92, Prague.

Vacek,J.(1991), "Similarity in geotechnics and calibration of models from equivalent materials", 32. Symp.on Rock Mechanics. Oklahoma. Balkema: 745-754.

Vacek,J.,Procházka,P.(1992), "Effect of adit and joint to failure mechanism of rock mass pillar", To appear in 9.Danube-Adria Symp.on Experimental Methods in Soil Mechanics, Trieste.